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Setting nutrient thresholds to support an ecological assessment based on nutrient enrichment, potential primary production and undesirable disturbance

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Abstract

The EU Water Framework Directive recognises that ecological status is supported by the prevailing physico-chemical conditions in each water body. This paper describes an approach to providing guidance on setting thresholds for nutrients taking account of the biological response to nutrient enrichment evident in different types of water. Indices of pressure, state and impact are used to achieve a robust nutrient (nitrogen) threshold by considering each individual index relative to a defined standard, scale or threshold.

These indices include winter nitrogen concentrations relative to a predetermined reference value; the potential of the waterbody to support phytoplankton growth (estimated as primary production); and detection of an undesirable disturbance (measured as dissolved oxygen). Proposed reference values are based on a combination of historical records, offshore (limited human influence) nutrient concentrations, literature values and modelled data. Statistical confidence is based on a number of attributes, including distance of confidence limits away from a reference threshold and how well the model is populated with real data.

This evidence based approach ensures that nutrient thresholds are based on knowledge of real and measurable biological responses in transitional and coastal waters.

Keywords: Nutrients; Primary productivity; Water Framework Directive; Classification

1. Introduction

The Water Framework Directive (WFD) represents a change in the management of water quality in Europe, with a shift from water quality targets based on chemistry (e.g. biological oxygen demand (BOD), ammonium and dissolved oxygen) to targets based on the ecological structure of natural systems (Pollard and Huxham, 1998). These ecological standards are to be set by reference to the ecological conditions expected in the absence or near absence of human impacts. The obligation set by the WFD is to achieve good ecological status in all waterbodies by 2015. The WFD states that ‘‘at high status the ‘general physico-chemical’ elements must be within their natural background ranges’’ while at ‘‘good ecological status nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified for the biological quality elements’’. The Directive identifies five physico-chemical elements that support the biological elements including transparency, thermal conditions, oxygenation conditions, salinity and nutrient conditions. The regulatory background is described in detail in Best et al. (2006) and EEB (2001). This paper focuses on the assessment of nutrient conditions in transitional and coastal waters for the WFD.

Nutrient enrichment and associated impacts have been documented extensively for many marine systems (Valiela et al., 1992; van Woesik et al., 1999; Gowen et al., 2002;

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Furnas, 2003; Nixon, 1995; Rabalais et al., 1996; Bricker and Stevenson, 1996; Newton et al., 2003; Nedwell et al., 2002). In northern temperate systems, excess nutrients may be utilised by primary producers such as phytoplankton and green macroalgae, and may result in an increase in productivity (Turner and Rabalais, 1994; Hecky and Kilham, 1988). Increased productivity may be expressed as higher biomass of primary producers, increased density of phytoplankton cells, prolonged phytoplankton blooms, extensive mats of opportunistic macroalgal species, or a shift in the species composition of the floral and faunal communities present (D'Elia, 1987; Nixon et al., 1996; Turner and Rabalais, 1994; Schramm and Neinhuisp, 1996; Lapointe and Matzie, 1996; Frodge et al., 1990; Shalovenkov, 2005). Increased density of phytoplankton in the water column may result in secondary effects due to decreased light availability (Schramm and Neinhuisp, 1996), such as loss of submerged aquatic vegetation due to the decreased light levels (Valiela et al., 1992) and reduced oxygen levels due to high microbial activity resulting from the abundance of dead and decaying organic matter (Clark et al., 1995; Diaz, 2001). Changes in the phytoplankton community structure may result in greater numbers of nuisance phytoplankton species being present (Tett, 1987), some of which can be toxic and may produce incidents of shellfish poisoning.

Prior to the introduction of the WFD, assessment and management of eutrophication (defined in terms of the undesirable consequences of nutrient enrichment) was based on the use of simple diagnostic tools (CSTT, 1994, 1997), such as the comparison of a bulk measurement of nutrient concentration (typically a winter mean) against a reference threshold. This reflected the method historically adopted for freshwaters, where an empirical approach provided a successful basis for managing eutrophication (Vollenweider, 1968, 1976; Carlson, 1977).

Relatively recent shifts in our conceptual understanding of eutrophication (see Cloern, 1999, 2001; Costanza and Mageau, 2001) indicate complex responses to nutrient inputs, including both direct and indirect responses, and the role of 'filters' in moderating the response or determining the sensitivity to nutrient enrichment. In marine systems, 'filters' such as light climate and advective losses, affect the susceptibility of different waterbodies to nutrient enrichment (Painting et al., 2005). This understanding is, in part, reflected in the more holistic assessment method developed by the Oslo-Paris convention (OSPAR). The OSPAR Common Procedure for the identification of eutrophication status (OSPAR, 2001, 2003) uses the exceedance of a baseline nutrient concentration as one step in a series of diagnostic steps for evidence of eutrophication. Reflecting the need for precaution, the presence of high nutrient concentrations is regarded as a potential cause for concern thus necessitating detailed assessment of biological response and the presence of any undesirable disturbance to the biology. Given our current understanding of the consequences of nutrient enrichment it is clear that, for any given aquatic situation, it is not possible to determine specific nutrient thresholds without reference to the biological response.

This revised understanding of the complex responses to nutrient enrichment in the marine environment has forced us to reconsider the way we define eutrophication. Eutrophication as defined by the EC (OSPAR, 2003) refers to the enrichment of waters by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance (resulting from anthropogenic enrichment by nutrients) to the balance of organisms present in the water. Bricker et al. (1999) emphasise eutrophication as a natural process by which productivity of a waterbody, as measured by organic matter, increases as a result of increasing nutrient inputs, but distinguishes between natural eutrophication and accelerated eutrophication where the nutrient overenrichment is caused by human related increases in the amount and composition of nutrients being discharged to the water body. This overenrichment results in the enhanced accumulation of organic matter, particularly algae, and a variety of impacts may result, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation and benthic fauna (Bricker et al., 1999; Ferreira, 2000). These impacts are interrelated and usually viewed as having a negative effect on water quality, ecosystem health, and human uses.

The definition of good status for nutrients in a WFD context therefore requires that nutrients, and/or overenrichment, have not caused a negative effect on the ecosystem health. Thus it is the evidence of levels of nutrient enrichment and production causing an undesirable disturbance that is required to meet the requirements of the WFD. This process is summarised in Fig. 1.

Linking nutrients to biology in the WFD classification tool is based on this cause and effect model (Fig. 1) and takes into account that nutrient concentrations in themselves are not undesirable, and must relate to some measurement(s) of functioning within the marine ecosystem. To fully integrate measurement of nutrient concentrations with a measurable biological response this paper will define a classification method which links levels of nutrient concentrations in UK surface waters classified by on WFD typology (Rogers et al., 2003) with measurements of phytoplankton production and disturbance.

2. Rationale

The nutrient classification tool is based on the integration of three indices of: nutrient concentrations, primary production and dissolved oxygen levels. Nutrient concentrations indicate the level of enrichment within the waterbody, primary production indicates the accelerated growth of marine plants in response to the nutrient concentrations, and measurements of dissolved oxygen can indicate if the increased production has impacted on the biology.

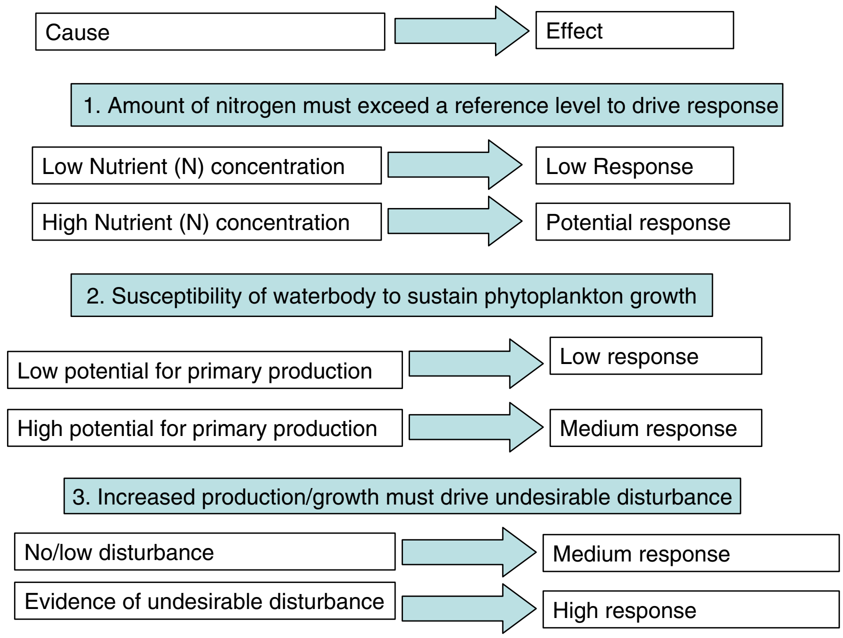

Fig. 1. Schematic diagram to describe processes linking nutrient enrichment with undesirable disturbance. Waterbody type will have some bearing on the susceptibility of the waterbody, which in turn, will drive the level of disturbance.

The three indices are based on

(1) Evidence of nutrient enrichment based solely on the calculation of an annual winter nitrogen concentration.
(2) Modelling of potential primary production based on a waterbody characteristics and light availability.
(3) Evidence of undesirable disturbance as measured by dissolved oxygen levels.

2.1. Evidence of nutrient enrichment

This index is based on exceedance of a predetermined threshold for winter nutrient concentrations. Nitrogen, rather than phosphorus, is considered the most likely limiting nutrient in many temperate coastal waters (Tsirtsis, 1995). However, Gowen et al. (1992) recognised that in low salinity environments phosphorus can be the limiting nutrients and that hypernutrification can result in a change in the limiting nutrient, such as silicate in the case of diatoms (Officer and Ryther, 1980). Future work on the link between phosphorus and silicate concentrations and biological response in marine waters may warrant inclusion of these nutrients in the classification process. At this time, primarily as an indicator of enrichment, not of status, nutrient concentrations will be assessed by dissolved inorganic nitrogen only.

Guidelines for assessment of nutrient enrichment follow the OSPAR guidelines (OSPAR, 2001, 2003) as agreed by all European member states in 2003 with comparison of a winter nutrient mean against a reference threshold. Assessment of nutrient enrichment is based on the same method for transitional and coastal waters, with calculations of thresholds for variable salinities. For transitional and coastal waters, nutrient enrichment is assessed by estimating a mean value for winter nutrient concentrations and comparing this to regionally specific reference concentrations (OSPAR, 2003). Initial classification into either high or good boundary classes is based on non-exceedance of predetermined thresholds. This metric is similar to that used within OSPAR criteria and ensures some degree of alignment between previous directives and WFD assessments.

In transitional and coastal waters, strong salinity gradients exist between the freshwater end and the marine waters due to riverine influences and must be taken into account in any assessment of nutrient enrichment in coastal systems. Assessments can compensate for the effect of salinity by normalising nutrient concentrations for salinity (Devlin and Painting, 2006). This is achieved by plotting the winter nutrient concentrations along the salinity gradient and calculating the mean winter value normalised to a specific salinity. In transitional and coastal waters, the salinity values for normalisation of winter DIN are taken as 25 and 32 respectively. In winter, defined as period when algal activity is lowest, dissolved nutrients should show conservative behaviour and, therefore, a good linear relationship with salinity i.e. nutrient concentrations should decrease with increasing salinity from fresh to coastal waters. Initial classification of the water bodies is then based on comparison of the normalised nutrient concentration against predetermined nutrient thresholds. Table 1 provides an example of nutrient thresholds calculated for England coastal and transitional waters based on normalised DIN values from a reference dilution line.

Table 1
Boundary conditions for all three indices for the five stages of status as set out in WFD classification (for coastal waters)

Classification		Index 1	Index 2	Index 3
	Attribute	Nutrient concentration	Production	Undesirable disturbance
	Description	Mean Winter DIN	Potential Primary Production	DO levels
	Units of measurement	uM	$g\ C\ m^{-2}\ y^{-1}$	mg/L
	Index	I_n **	I_{pp}	I_{do}
High		$\mathbf{I_n} \leq 12\mu M$	n\a	n\a
Good		$\mathbf{I_n} \leq 18\mu M$	n\a	n\a
Good			$(\mathbf{I_n} \geq 30\mu M)$ & $(\mathbf{I_{pp}} < 300)$	n\a
Moderate			$(\mathbf{I_n} \geq 30\mu M)$ & $(\mathbf{I_{pp}} \geq 300)$	$\mathbf{I_{do}} > 5 mg/l$
Poor			$(\mathbf{I_n} \geq 30\mu M)$ & $(\mathbf{I_{pp}} \geq 300)$	$\mathbf{I_{do}} \leq 5 mg/l$
Bad			$(\mathbf{I_n} \geq 30\mu M)$ & $(\mathbf{I_{pp}} \geq 300)$	$\mathbf{I_{do}} \leq 2 mg/l$

Boundary classification is based on deviation from reference conditions, as classification progresses through the three indices. The dotted line represents boundary between good and moderate in relation to management action point.

2.2. Calculation of primary production

The relationship between nitrogen loading and phytoplankton biomass or production is not clear for marine environments (Hecky and Kilham, 1988) and requires an understanding of dynamic relationships between nitrogen supply and primary production (see Boynton et al., 1982). Production in marine waters is influenced by the supply of nutrients, light, temperature, flow regime, turbidity, zooplankton grazing and toxic substances. Low rates of annual primary production may indicate low susceptibility to enrichment (Cloern, 2001; Bricker et al., 1999) while high rates of annual primary production represent higher susceptibility, possibly resulting in symptoms associated with undesirable disturbance. Rodhe (1969) proposed net annual primary production thresholds for assessing eutrophic status of 'naturally eutrophic' and 'polluted' freshwater (>75 and >350 $g\ C\ m^{-2}\ y^{-1}$respectively). For coastal marine waters, Nixon (1995) proposed a similar scale for assessing trophic status where production rates of greater than 300 $g\ C\ m^{-2}\ y^{-1}$ represented eutrophic status. It is important to note that waterbodies may be identified as being eutrophic by this scale may not necessarily show any signs of eutrophication. Additional attributes will need to be considered to assess the negative impacts of the high primary production.

The second metric of the tool estimates potential primary production for a waterbody and compares this value to a trophic threshold. Estimates of potential primary production are obtained from a simple screening model (Fig. 2), which uses equilibrium nutrient concentrations and light limited growth rates to calculate production (Tett et al., 2003). Site-specific parameters used as inputs to the model include volume and depth of the waterbody, exchange rates, microplankton loss rates, and information on underwater optics (24-h mean surface PAR, attenuation coefficients, and optical depth). Model structure and information flow are detailed in Painting et al. (2006). Detailed explanations of the parameters and the values assigned to them, are given by Tett et al. (2003).

2.3. Concentration of dissolved oxygen levels

Work by (Anon, 2004; Tett et al., 2006) reports on the definition of undesirable disturbance as a perturbation of a marine ecosystem that appreciably degrades the health or threatens the sustainable human use of that ecosystem. Measurements of minimum concentrations of oxygen can be very successful as indicators of dystrophic condition and can indicate the effectiveness of coupling between primary producers and their immediate consumers (Best et al., 2006; Tett et al., 2004).

In the WFD, dissolved oxygen (DO) levels are based on criteria set for fish in transitional waters which provide limits to the optimum conditions for juvenile fish within the freshwater reaches of estuaries (Best et al., 2006). When DO concentrations fall below 5 mg/l (156 µmol/l), sensitive species of fish and invertebrates can be negatively impacted. At levels below 2.5 mg/l most fish are negatively impacted (Frodge et al., 1990). Reduced levels of DO can also impact biogeochemical reactions (Diaz, 2001). Low concentrations of DO over prolonged periods may slow rates of nitrification and denitrification (Kemp et al., 1990), while rapid alternation between oxic and hypoxic conditions can enhance denitrification (Knowles, 1982).

The fate and behaviour of dissolved oxygen is of critical importance to marine organisms in determining the severity of adverse impacts. Stiff et al. (1992) and Nixon et al. (1996) identified crustacea and fish as the organisms most sensitive to reduced DO levels, with the early life stages of fish being particularly sensitive. For estuarine fish, Stiff et al. (1992) suggested a minimum DO requirement of 3–5 mg/l. Oxygen deficiency is widely used as an indirect assessment parameter for nutrient enrichment. OSPAR (2003) notes that oxygen deficiency can be induced by

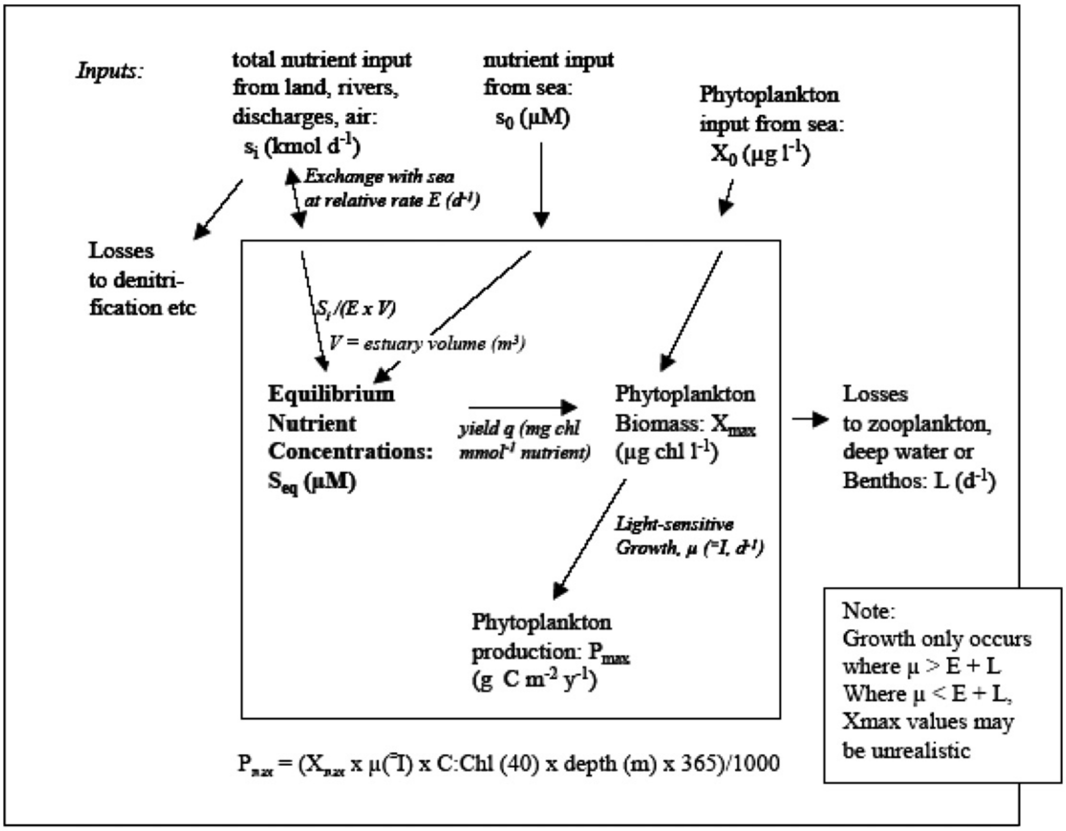

Fig. 2. Conceptual diagram to indicate model structure and information flow from Painting et al. (2006).

decaying algal blooms associated with enrichment, especially in sedimentation areas, areas with long residence times of water, and in shallow areas with attached nuisance algae. Consequently oxygen deficiency "during the growing season" is a category 3 effect under OSPAR, with 2–6 mg/l oxygen defined as a "deficiency" and less than 2 mg/l as "acute toxicity" (OSPAR, 2003). Oxygen concentrations above 6 mg/l are considered to cause no problems.

We have use dissolved oxygen concentrations as a final step to indicate the extent of disturbance, or alternately as an index of the extent to which the classification moves beyond moderate status.

3. Description of thresholds

Reference levels were calculated to establish thresholds for each index, and combined for the final classification (Table 2).

3.1. Dissolved inorganic nitrogen

To allow for natural variability and the absence of pristine sites and/or long term historical datasets, the assessment level for the good/moderate boundary was defined as the concentration 50% above the salinity-related and/or area-specific background concentration as set out in

Table 2
Calculation of boundary thresholds for winter dissolved inorganic nitrogen (DIN) for (UK) coastal and transitional waters based on regional reference levels

	Calculation of reference conditions	Calculation of high threshold (T_1)	Calculation of good threshold (T_2)
Transitional waters	Based on a normalised DIN concentration (salinity = 25) based on reference dilution line (Devlin and Painting, 2006)	Regionally agreed reference level (20 μM)	50% elevation on normalised reference level −30 μM
Coastal waters	Based on a normalised DIN concentration (salinity = 32) based on reference dilution line (Devlin and Painting, 2006)	Regionally agreed reference level (13 μM)	50% elevation on normalised reference level −20 μM

The boundary threshold for "good" is calculated on a 50% deviation away from the reference level (to allow for the inherent natural variability associated with nutrient concentrations).

Table 3
Summary of the three indices used in the classification process

	First index (I_n) – nutrient enrichment	Second index (I_{pp}) – potential primary production	Third index (I_{do}) – evidence of undesirable disturbance
Description of attribute	Dissolved Inorganic Nitrogen is defined by the sum of inorganic nitrogen (nitrite and nitrate) and ammonia (NH4) Winter is defined by data collected in the months of November, December, January and February inclusive	Calculation of primary production is based on an estimate of nitrogen production based on nutrient inputs, typology, irradiance and light attenuation. (Painting et al., 2006)	Dissolved oxygen concentration should not fall below threshold level (mg/l) at the freshwater end member for more than on 5% of the sampling occasions over the 6 year return period
Units	μM	$g\,C\,m^{-2}\,y^{-1}$	mg/l
Reference condition thresholds	Thresholds will be based on the salinity gradient between baseline Atlantic shelf concentrations of 10 mM N, (Gowen et al., 2002) and a reference freshwater concentrations (Wither, pers comm.)	Trophic status as defined by Nixon (1995)	Thresholds in line with the Dissolved Oxygen element based on stress induced DO levels for fish and benthic invertebrates
Statistical analysis	Mean nutrient concentration is calculated from all samples collected over the winter period within a waterbody Exceedance is based on the location of the mean relative to the thresholds	Modelled calculation of primary production, calculated as an annual mean	Thresholds are based on 5%-ile, i.e. they should be above the threshold levels for 95% of the sampling occasions Frequent spot sample measurements from many sites throughout a waterbody allow a confident assessment to be made with

the first OSPAR Comprehensive Procedure (OSPAR, 2003, see Painting et al., 2005). Normalised reference concentrations were taken from the reference dilution plots at salinities of 25 for transitional waters and salinities of 32 for coastal waters.

Reference concentrations for DIN in freshwater were taken from a pristine catchment of the West Coast of UK and reference conditions for offshore waters were based on the average winter Atlantic water in offshore waters surrounding the UK (Gowen et al., 2002). Details of the attributes are further described in Table 3. Initial nutrient assessment is calculated by:

$$I_{n\ (\mathrm{CW\ or\ TW})} : \leqslant (T_1 \text{ or } T_2) = \text{high or good classification} \quad (1)$$

$$I_{n\ (\mathrm{CW\ or\ TW})} : > (T_2) - \text{moves into 2nd index} \quad (2)$$

where I_n is the first index (dissolved inorganic nitrogen) calculated as a mean Winter DIN concentration and T_1 and T_2 equates to the first or second nutrient threshold as defined for that regional area.

3.2. Potential primary production

The trophic scale proposed by Nixon (1995) was applied, and a threshold for eutrophic status was set at $300\,g\,C\,m^{-2}\,y^{-1}$. Tett et al. (2004) discusses the possibility of dystrophy that should be considered above a net microplankton production of $200\,g\,C\,m^{-2}\,y^{-1}$. This is lower than Nixon's threshold of $300\,g\,C\,m^{-2}\,y^{-1}$ for eutrophic conditions, but is a precautionary value, and its exceedance only diagnoses the need for further study, especially for planktonic and benthic community structures. It is likely that dystrophy will in fact only occur at much higher levels of production, and passing the threshold does not in itself diagnose desirable disturbance. This index defines the boundary between good and moderate status, which relates to an action requirement, consequently the boundary condition is set at the higher level of trophic status ($300\,g\,C\,m^{-2}\,y^{-1}$). If potential production is estimated to be below this threshold then the classification remains at good status (Eq. (3)). Exceedance of this threshold moves the classification into "at least" moderate status, requiring some form of rehabilitation or response (Eq. (4))

$$I_{\mathrm{pp\ for\ coastal\ waters}}: \leqslant (T_3) = \text{good classification} \quad (3)$$

$$I_{\mathrm{pp\ for\ coastal\ waters}}: > (T_3) = \text{moves into 3rd index} \quad (4)$$

where I_{pp} represents the second index, calculated as annual primary production (Painting et al., in press) and T_3 equates to a trophic threshold of $300\,g\,C\,m^{-2}\,y^{-1}$.

3.3. Undesirable disturbance

Criteria for dissolved oxygen in marine waters have been developed from simple single attribute limits for the purposes of classification schemes. Dissolved oxygen levels greater than 5 mg/l seem to be sufficient for fish and invertebrate survival, and concentrations above this level equate to a moderate status (Eq. (5)). When levels fall below 5 mg/l, the final classification drops to poor (Eq. (6)), and further declines of DO to below 2 mg/l would result in a bad classification (Eq. (7))

$$I_{do}: \leqslant (T_4) = \text{moderate classification} \quad (5)$$

$$I_{do}: > (T_4) = \text{poor classification} \quad (6)$$

$$I_{do}: > (T_5) = \text{bad classification} \quad (7)$$

where I_{do} represents the third index (dissolved oxygen) Nixon (1995) is a measurement of annual dissolved oxygen

(Best et al., 2006) and T_4 and T_5 equates to dissolved oxygen thresholds known to impact on fish and benthic communities. It is worth noting that there are other ecological aspects of "undesirable disturbance" including shifts to more opportunistic species (McGlathery, 2001; Morand and Briand, 1996), changes to the submerged aquatic vegetation (SAV) and transparency (Den Hartog, 1994; Hauxwell et al., 2000; Bricker et al., 1999), increased harmful algal bloom frequency (HABs) (reviewed in Tett et al., 2006) and changes to the benthic and plankton trophic state (Borja et al., 2003a; Borja et al., 2000; Talling and Heaney, 1988). Detailing other biological responses in combination with the oxygen measurements will support the outcomes of the final classification. In the absence of dissolved oxygen measurements, other secondary biological responses could be sufficient to demonstrate undesirable disturbance.

4. Overall classification

An overall classification of ecological status based on nutrient thresholds uses a combination of all three indices described above (Fig. 3). Attribute information, reference descriptions, measurement units and statistical analysis associated with each index is outlined in Table 3.

The classification proposed here bases assessment on a pressure (nutrient enrichment) driving some aspect of disturbance in the biology (response). Nutrient concentrations below reference levels represent low nutrient environments, and limits eutrophication symptoms relative to overenrichment. Low nutrient concentrations yield low potential for growth and results in a "high" or "good" classification. Any exceedance of the nutrient threshold necessitates calculation of potential primary production (I_{pp}). High turbidity and/or low light conditions within a waterbody may limit phytoplankton growth within a nutrient enriched environment and estimates of production below Nixon's thresholds of 300 g C m^{-2} y^{-1} result in a "good" classification despite the high nutrient concentrations. Classification as "moderate" is based on evidence of both nutrient enrichment and potential primary production exceeding Nixon's eutrophic threshold. Once evidence for enrichment and production has been established, classification progresses into the "moderate" class and requires the calculation of the third index to determine if an undesirable disturbance can be measured. For classification to fall below "moderate" a measurable disturbance in the ecological functioning must be demonstrated. Any evidence of disturbance as measured by reduced DO levels below a threshold will equate to a "poor" or "bad" classification.

5. Conclusion

A classification process based on nutrient enrichment must look beyond a simple measurement of nutrient concentrations. The classification process proposed here relates high nutrient levels to the potential of the waterbody to support algal production and the presence of an undesirable disturbance which can be related to nutrient enrichment. Evidence of all three is required before a waterbody can be classified as "below moderate" and requires immediate management action. One of the first signs of eutrophication is increased productivity of a water body, as a result of increasing nutrient inputs. Therefore evidence of only 2 of the indices (high nutrients and high primary production) is needed for a "moderate" classification, which requires management action of reduction or rehabilitation.

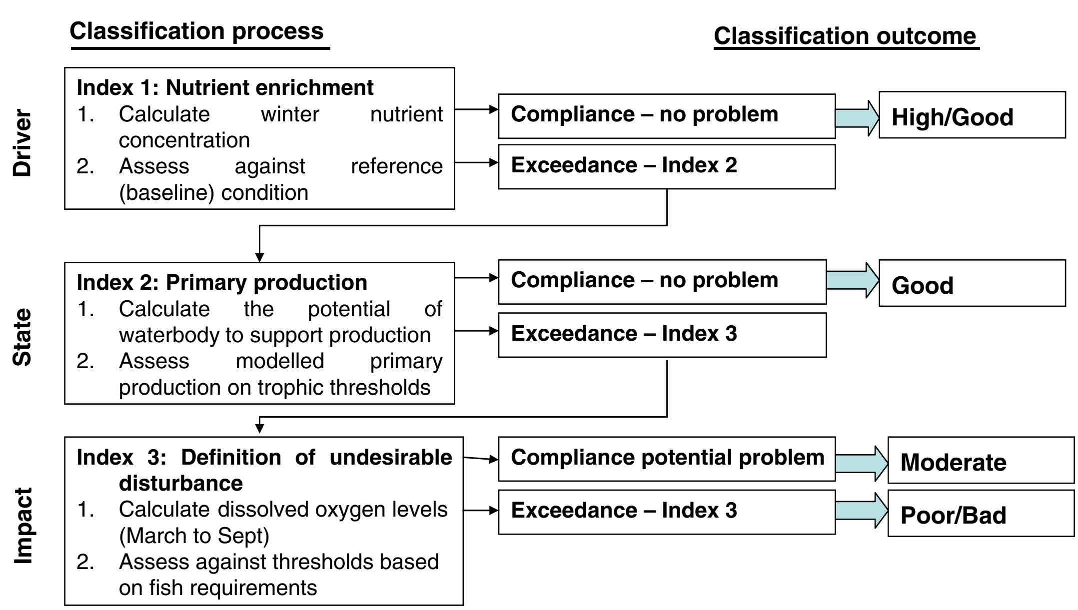

Fig. 3. Representation of classification process, linking WFD classification boundaries with OSPAR assessment categories. Wide arrows represent a final outcome, with thin arrows moving classification into next index.

Marine eutrophication is a critical environmental concern and the subject of continuing high policy interest for the nations of North West Europe (EEA, 1999, 2001; Boesch, 2002). EU policy is built on scientific experience across the member states regarding the extent of environmental problems in European waters and it is critical that a common view is developed so that effective, proportionate European policy can develop. This is particularly important as the social and economic costs involved with the management of nutrients is relatively high and there must be assurance that measures will lead to tangible environmental benefit. It is of sound benefit to UK policy and environmental management decisions that any ecological assessment is based on reliable evidence on the interactions between pressures (nutrients), state (production) and impact (disturbance to the biology).

Disclaimer

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